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APPLIED MATHEMATICS

(6) CALCULATION OF NATURAL FREQUENCIES AND NORMAL MODES OF VIBRATION FOR A COMPOUND ISOLATION MOUNTING SYSTEM,

(10) Raymond R. T. McGoldrick.

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CALCULATION OF NATURAL FREQUENCIES AND NORMAL MODES OF VIBRATION FOR A COMPOUND ISOLATION MOUNTING SYSTEM

by

R.T. McGoldrick

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NOTATION

The notation used in this report conforms with that of Reference 1, and the inch-pound-second system of units is retained. The only modifications introduced are subscripts or superscripts required to distinguish between the cradle (Body 1 or I) and the assembly (Body 2 or II). The two sets of axes used are parallel to each other but are otherwise arbitrary and need not be principal axes of inertia. Illustrative samples are given here.

$F_x^{I,I}$	Force in the x-direction exerted on Body I by the upper set of mountings due to a general displacement of Body I with Body II held fixed
$F_y^{I,II}$	Force in the y-direction exerted on Body II due to a general displacement of Body I with Body II held fixed
$F_z^{II,I}$	Force in the z-direction exerted on Body I due to a general displacement of Body II with Body I held fixed
I_x^{I}	Mass moment of inertia of the cradle (Body I) with respect to $0_1 x_1$
I_{xy}^{II}	Mass product of inertia of the assembly (Body II) with respect to $0_2 x_2$ and $0_2 y_2$
K_{uv}^{I}	Spring constant of the entire lower set of mountings relating a displacement of the cradle in the y-direction with the restoring force in the x-direction, and conversely
$K_{u\beta}^{II}$	Spring constant of the entire upper set of mountings giving either the restoring force acting on the assembly in the x-direction due to unit rotation of the assembly about $0_2 x_2$ or the restoring torque about $0_2 y_2$ due to a unit displacement of the assembly in the x-direction, the cradle being held fixed in either case
K_{vw}^{III}	Spring constant of the entire upper set of mountings relating a displacement of the cradle in the z-direction with the restoring force acting on the cradle in the y-direction, the assembly being held fixed.
K_{uv}^{IV}	$K_{uv}^{I} + K_{uv}^{III}$
$M_x^{I,II}$	Moment exerted on Body II with respect to $0_2 x_2$ due to a general displacement of Body I with Body II held fixed
$M_y^{II,II}$	Moment exerted on Body II with respect to $0_2 y_2$ due to a general displacement of Body II with Body I held fixed
$M_z^{II,I}$	Moment exerted on Body I with respect to $0_1 z_1$ due to a general displacement of Body II with Body I held fixed

m_1	Mass of the cradle (Body 1)
m_2	Mass of the assembly (Body 2)
u_1, v_1, w_1	Small displacements of the center of mass of Body I in the x-, y-, and z-directions, respectively
α_2, β_2, γ_2,	Small rotations of Body II about $0_2\,x_2$, $0_2\,y_2$, and $0_2\,z_2$, respectively

ABSTRACT

The natural frequencies and normal modes of vibration of a compound mounting system are determined. The system consists of an assembly supported by a set of isolation mountings carried by a cradle which is, in turn, supported by another set of isolation mountings attached to the hull of a ship. The dynamical equations of motion of the system and the numerical solution of a specific example are given.

INTRODUCTION

The subject of isolation mounting of shipboard equipment as applied to single assemblies is discussed in detail in Reference 1.* There the general dynamical equations for the system, consisting of a rigid assembly supported by a set of mountings of arbitrary orientation, are derived, and it is pointed out that the normal modes and natural frequencies of this system, which has six degrees of freedom, can be found by the use of a digital computer. Although Reference 1 points out the advantages of designing such systems so that planes of vibrational symmetry exist, the general problem which was coded was subject to no restrictions as to symmetry. This permitted the use of a set of reference axes with arbitrary orientation. The only restriction was that the origin of the coordinates be located at the center of gravity of the mounted assembly in its rest position.

Although compound isolation mounting systems have been in use for some time, they have become of increasing interest since the publication of Reference 1. In the compound system a cradle or rigid frame is interposed between the hull and the bases of the mountings which support the assembly and the cradle is, itself, supported by another set of mountings whose bases are secured to the hull structure.

The Bureau of Ships requested the David Taylor Model Basin to develop methods for calculating the normal modes and natural frequencies of such systems.[2] Accordingly, this report is concerned with the extension of the analyses given in Reference 1 to compound systems. The treatment of the same problem by the electrical analogy is discussed in Reference 3.

DYNAMICAL EQUATIONS

The system under consideration is shown schematically in elevation in Figure 1. The upper body, whose mass is m_2, comprises the entire assembly. The lower body, whose mass is m_1, comprises the cradle. In this schematic representation two pairs of coil springs are shown. Each pair represents a complete set of isolation mountings not limited in number.

*References are listed on page 12.

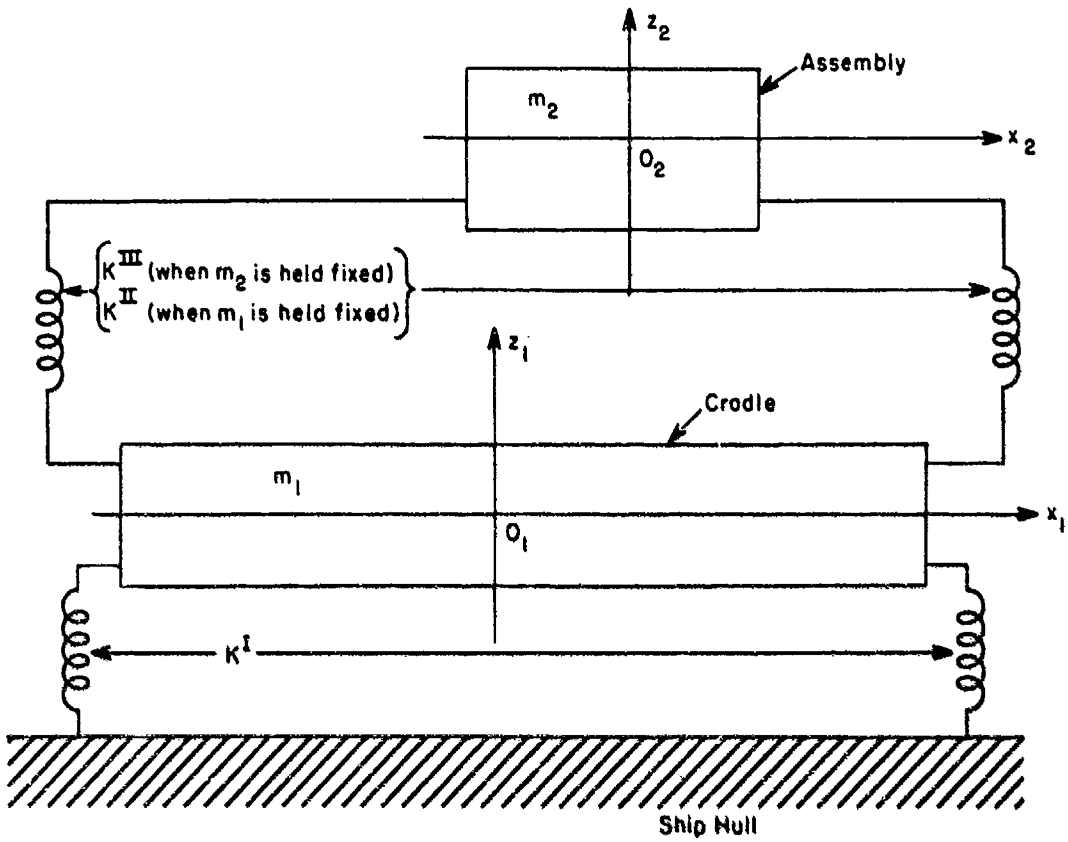


Figure 1 – Schematic Elevation of Compound Isolation Mounting System

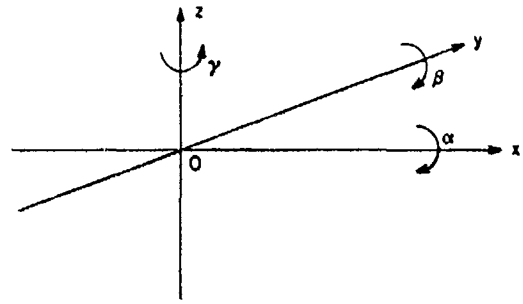
The lower pair of springs represents the set between the cradle and the hull, whereas the upper pair represents the set between the cradle and the assembly.

In Figure 1 the system is assumed to be in its rest position, under gravity, with the mountings unlocked. For this condition a fixed (in space) set of rectangular coordinate axes with origin at the center of gravity is established for each body. Only the x- and z-axes appear in Figure 1, but each set is actually a set of right-hand axes of the type indicated in Figure 2. Although there is no restriction as to the orientation of the axes with respect to either body, the problem has been coded on the assumption that the two sets of axes are parallel.

Obviously, the cradle is subject to forces and moments exerted by both sets of mountings, whereas the assembly is affected by the upper set only. Furthermore, it is clear that, if the assembly is held fixed, the cradle is subject to the analysis given in Appendix 5 of Reference 1 for the one-body system. In this case, the two sets of mountings combine into a single set since the assembly then in effect becomes part of the hull.

Except for obvious subscript and superscript designations, the notation in this report conforms with that of Reference 1, and the inch-pound-second system of units is retained. Thus the K's are spring constants of entire sets of mountings; I_x^1 is the mass moment of inertia of the cradle with respect to 0_1x_1; I_{xy}^{II} is the mass product of inertia of the assembly with respect to 0_2x_2 and 0_2y_2; and m_1 is the mass of the cradle.

Figure 2 – Right-Hand Coordinate System Used in Analysis



As in Reference 1, k_a is the axial spring constant and k_r is the radial spring constant of an individual mounting. It should be noted at this point, however, that, whereas the coordinates of the effective points of attachment of the individual lower mountings need be specified only with respect to the axes x_1, y_1, and z_1, the coordinates of the effective points of attachment of the individual upper mountings must be given with respect to x_2, y_2, and z_2 as well as x_1, y_1, and z_1 because in the analysis presented in this report two sets of K's are used for the upper set of mountings, each one derived by holding one of the bodies fixed.

The K^{I}'s are the spring constants of the entire lower set of mountings with respect to axes whose origins are at the center of gravity of the cradle; hence, they are evaluated exactly as in the one-body problem discussed in Appendix 5 of Reference 1.

The K^{III}'s are the spring constants of the entire upper set of mountings evaluated with respect to the same axes as the K^{I}'s, the assembly being considered held fixed.

The K^{II}'s are the spring constants of the entire upper set of mountings with respect to axes with origins at the center of gravity of the assembly, the cradle being considered held fixed.

With $K^{IV} = K^{I} + K^{III}$ the combined set of mountings is reduced to one set since, if the assembly is held fixed, the cradle then comprises a system of the type treated in Reference 1.

The restrictions noted on page 99 of Reference 1 with regard to torques developed in the mountings themselves are retained, but it is noted here that, if mountings are to be used which do not have polar symmetry but whose principal elastic axes have been located, they may be treated as three separate mountings, each having only k_a (that is $k_r = 0$). In this case there must be specified the direction angles which each of the elastic axes makes with the coordinate axes chosen, as well as the three separate values of k_a for each mounting.

Likewise, as previously, the analysis is valid only for small motions about the equilibrium position and within the linear range of the elastic properties of the mountings. It is implied that the moments and products of inertia of the bodies relative to the fixed axes do not change significantly within the range of vibration amplitudes considered.

Within the range of small motions assumed, the elastic forces and moments resulting from a general displacement of both bodies will be the sum of the forces and moments arising from any linear combination of displacements that yields the same resultant displacements. A convenient combination of displacements is: first, a displacement of the cradle to its final position with the assembly held fixed; and, second, a displacement of the assembly to its final position with the cradle held fixed in its equilibrium position. For each of these, the forces and moments acting on the body that has been displaced are readily evaluated once the set of elastic constants of the entire set of mountings is evaluated for the assumed condition.

Specifically, when the cradle is held fixed, the forces and moments acting on the assembly can be derived by the equations given in Reference 1 provided the K^{II}'s for the upper set of mountings are evaluated according to the given formulas with respect to axes whose origins are at the center of gravity of the assembly. Similarly, when the assembly is held fixed, the forces and moments acting on the cradle are given by the equations in Reference 1 provided the K^{I}'s and K^{III}'s are evaluated according to the formulas given in Reference 1. Obviously, in this case the upper and lower sets of mountings may be regarded as a single set $K^{IV} = K^{I} + K^{III}$.

The dynamical equations require the evaluation of the forces in the x-, y-, and z-directions and of the moments about $0x$, $0y$, and $0z$ for each body when the system is oscillating in any normal mode. Since the two sets of axes are parallel, the force components which the upper set of mountings exerts on the cradle are equal and opposite to those which it exerts on the assembly. However, since the axes have separate origins, the moments exerted by the upper set of mounts on the cradle will not be equal and opposite to the moments on the assembly.

Hence, before the dynamical equations for the compound system can be written, it is necessary to establish the equations for the transfer of moments exerted by the upper set of mountings from one body to the other.

Let a moment exerted on Body II (with respect to axes x_2, y_2, z_2) due to motion of Body I with Body II held fixed be designated $M^{I,II}$, and the moment on Body II with respect to the same axes due to the motion of Body II with Body I held fixed be designated $M^{II,II}$. Likewise, let the moment on Body I (with respect to x_1, y_1, z_1) due to the motion of Body II with Body I held fixed by $M^{II,I}$, and the moment on Body I due to the motion of Body I with Body II held fixed by $M^{I,I}$.

Let the forces be similarly designated, but recall that

$$F^{I,I} = -F^{I,II}$$

and

$$F^{II,I} = -F^{II,II}$$

In deriving the moment relations it must be recalled that the equal and opposite forces exerted by any mounting are considered to act at the effective point of attachment of that mounting. It should be noted that such points do not appear in Figure 1, which is only schematic. The latter point, which is discussed in detail in Reference 1, is common to both bodies when the part of the mounting attached to either body is regarded as integral with that body. Hence, the forces which any mounting of the upper set exerts on the two bodies are not only equal and opposite in direction but act through the same point if small vibratory displacements are neglected. Torques developed within the mountings themselves are neglected here. Then, if the superscript I is used to denote the coordinates of the origin 0_1 with respect to axes x_2, y_2, z_2 and the superscript II is used to denote the coordinates of the origin 0_2 with respect to axes x_1, y_1, z_1, the following equations for transfer of moments applied by the upper set of mountings result.

$$
\begin{aligned}
M_x^{II,I} &= -(M_x^{II,II} + F_z^{II,II}\, y^{II} - F_y^{II,II}\, z^{II}) \\
M_y^{II,I} &= -(M_y^{II,II} + F_x^{II,II}\, z^{II} - F_z^{II,II}\, x^{II}) \\
M_z^{II,I} &= -(M_z^{II,II} + F_y^{II,II}\, x^{II} - F_x^{II,II}\, y^{II}) \\
M_x^{I,II} &= -(M_x^{I,I} + F_z^{I,I}\, y^{I} - F_y^{I,I}\, z^{I}) \\
M_y^{I,II} &= -(M_y^{I,I} + F_x^{I,I}\, z^{I} - F_z^{I,I}\, x^{I}) \\
M_z^{I,II} &= -(M_z^{I,I} + F_y^{I,I}\, x^{I} - F_x^{I,I}\, y^{I})
\end{aligned}
$$

All forces appearing in these equations are exerted only by the upper set of mountings and are the resultant for that entire set.

Let it be assumed that 0_1 falls on 0_2. Then, since all the forces on the two bodies are equal and opposite and all the lever arms are in this case identical, the net moments will also be equal and opposite; that is, $M^{II,I} = -M^{II,II}$. The additional terms on the right side of the equations arise when 0_1 is shifted to the position x^I, y^I, z^I and it is noted that $x^I = -x^{II}$; $y^I = -y^{II}$; $z^I = -z^{II}$.

There will be twelve dynamical equations each obtained by equating the time rate of change of linear or angular momentum of one of the bodies to the resultant force or moment acting on that body. The rates of change of momentum when expressed in algebraic form are identical with those used for the one-body problem in Reference 1 such as $-m u \omega^2$ and $(-I_x \alpha\omega^2 + I_{xy}\, \beta\omega^2 + I_{xz}\, \gamma\omega^2)$ appearing in the equations at the top of page 104 of Reference 1.

The force and moment expressions for the compound or two-body problem can be written down at once when it is remembered that each force or moment is the resultant of the force or moment developed first by holding Body II fixed and moving Body I to its final position and then by holding Body I fixed and moving Body II to its final position. The rules for transferring forces and moments from one body to the other have been given.

As an illustration, the equation for time rate of change of rectilinear momentum of Body I in the x-direction is:

$$
m_1 \ddot{u}_1 = - \left[\begin{array}{l}
(K_{uu}^{I} + K_{uu}^{III})\, u_1 + (K_{uv}^{I} + K_{uv}^{III})\, v_1 \\
+ (K_{uw}^{I} + K_{uw}^{III})\, w_1 + (K_{u\alpha}^{I} + K_{u\alpha}^{III})\, \alpha_1 \\
+ (K_{u\beta}^{I} + K_{u\beta}^{III})\, \beta_1 + (K_{u\gamma}^{I} + K_{u\gamma}^{III})\, \gamma_1 \\
- K_{uu}^{II}\, u_2 - K_{uv}^{II}\, v_2 - K_{uw}^{II}\, w_2 - K_{u\alpha}^{II}\, \alpha_2 \\
- K_{u\beta}^{II}\, \beta_2 - K_{u\gamma}^{II}\, \gamma_2
\end{array} \right]
$$

The equations for time rate of change of angular momentum contain more terms than those for rectilinear momentum but are obtained by the same general procedure. Thus

$$
I_x^{I} \ddot{\alpha}_1 - I_{xy}^{I} \ddot{\beta}_1 - I_{xz}^{I} \ddot{\gamma}_1 = - \left[\begin{array}{l}
(K_{u\alpha}^{I} + K_{u\alpha}^{III})\, u_1 + (K_{v\alpha}^{I} + K_{v\alpha}^{III})\, v_1 \\
+ (K_{w\alpha}^{I} + K_{w\alpha}^{III})\, w_1 + (K_{\alpha\alpha}^{I} + K_{\alpha\alpha}^{III})\, \alpha_1 \\
+ (K_{\alpha\beta}^{I} + K_{\alpha\beta}^{III})\, \beta_1 + (K_{\alpha\gamma}^{I} + K_{\alpha\gamma}^{III})\, \gamma_1
\end{array} \right] + M_x^{II,I}
$$

where

$$
M_x^{II,I} = -(M_x^{II,II} + F_z^{II,II}\, y^{II} - F_y^{II,II}\, z^{II})
$$

$$
= - \left[\begin{array}{l}
- K_{u\alpha}^{II}\, u_2 - K_{v\alpha}^{II}\, v_2 - K_{w\alpha}^{II}\, w_2 \\
- K_{\alpha\alpha}^{II}\, \alpha_2 - K_{\beta}^{II}\, \beta_2 - K_{\alpha\gamma}^{II}\, \gamma_2 \\
+ y^{II} \left(\begin{array}{l} - K_{uw}^{II}\, u_2 - K_{vw}^{II}\, v_2 - K_{ww}^{II}\, w_2 \\ - K_{w\alpha}^{II}\, \alpha_2 - K_{w\beta}^{II}\, \beta_2 - K_{w\gamma}^{II}\, \gamma_2 \end{array} \right) \\
- z^{II} \left(\begin{array}{l} - K_{uv}^{II}\, u_2 - K_{vv}^{II}\, v_2 - K_{wv}^{II}\, w_2 \\ - K_{v\alpha}^{II}\, \alpha_2 - K_{v\beta}^{II}\, \beta_2 - K_{v\gamma}^{II}\, \gamma_2 \end{array} \right)
\end{array} \right]
$$

When the terms with second derivatives in time are converted to algebraic form and all terms are transferred to the left-hand side of the equations, the complete set of twelve dynamical equations yields the frequency determinant shown on page 7.

The 12 by 12 matrix is symmetrical with respect to the main diagonal, which implies that the K^{II}'s can be expressed in terms of the K^{III}'s and vice versa.

The digital solution of the problem follows the scheme used for the one-body problem and discussed in Reference 1.

12 × 12 Matrix

	u_1	v_1	w_1	α_1	
u_1	$K_{uu}^{IV} - m_1\,\omega^2$	K_{uv}^{IV}	K_{uw}^{IV}	$K_{u\alpha}^{IV}$	$K_{u\beta}^{IV}$
v_1	K_{uv}^{IV}	$K_{vv}^{IV} - m_1\,\omega^2$	K_{vw}^{IV}	$K_{v\alpha}^{IV}$	$K_{v\beta}^{IV}$
w_1	K_{uw}^{IV}	K_{vw}^{IV}	$K_{ww}^{IV} - m_1\,\omega^2$	$K_{w\alpha}^{IV}$	$K_{w\beta}^{IV}$
α_1	$K_{u\alpha}^{IV}$	$K_{v\alpha}^{IV}$	$K_{w\alpha}^{IV}$	$K_{\alpha\alpha}^{IV} - I_z^1\,\omega^2$	$K_{\alpha\beta}^{IV}$ +
β_1	$K_{u\beta}^{IV}$	$K_{v\beta}^{IV}$	$K_{w\beta}^{IV}$	$K_{\alpha\beta}^{IV} + I_{xy}^1\,\omega^2$	$K_{\beta\beta}^{IV}$
γ_1	$K_{u\gamma}^{IV}$	$K_{v\gamma}^{IV}$	$K_{w\gamma}^{IV}$	$K_{\alpha\gamma}^{IV} + I_{xz}^1\,\omega^2$	$K_{\beta\gamma}^{IV}$
u_2	$-K_{uu}^{III}$	$-K_{uv}^{III}$	$-K_{uw}^{III}$	$-K_{u\alpha}^{III}$	$-K_{u\beta}^{III}$
v_2	$-K_{uv}^{III}$	$-K_{vv}^{III}$	$-K_{vw}^{III}$	$-K_{v\alpha}^{III}$	$-K_{v\beta}^{III}$
w_2	$-K_{uw}^{III}$	$-K_{vw}^{III}$	$-K_{ww}^{III}$	$-K_{w\alpha}^{III}$	$-K_{w\beta}^{III}$
α_2	$K_{uv}^{III}\,z^1 - K_{uw}^{III}\,y^1 - K_{u\alpha}^{III}$	$K_{vv}^{III}\,z^1 - K_{vw}^{III}\,y^1 - K_{v\alpha}^{III}$	$K_{vw}^{III}\,z^1 - K_{ww}^{III}\,y^1 - K_{w\alpha}^{III}$	$K_{v\alpha}^{III}\,z^1 - K_{w\alpha}^{III}\,y^1 - K_{\alpha\alpha}^{III}$	$K_{\alpha\beta}^{III}$
β_2	$K_{uw}^{III}\,z^1 - K_{uu}^{III}\,x^1 - K_{u\beta}^{III}$	$K_{vw}^{III}\,z^1 - K_{uv}^{III}\,x^1 - K_{v\beta}^{III}$	$K_{ww}^{III}\,z^1 - K_{uw}^{III}\,x^1 - K_{w\beta}^{III}$	$K_{w\alpha}^{III}\,z^1 - K_{u\alpha}^{III}\,x^1 - K_{\alpha\beta}^{III}$	$K_{w\beta}^{III}$
γ_2	$K_{uu}^{III}\,y^1 - K_{uv}^{III}\,x^1 - K_{u\gamma}^{III}$	$K_{uv}^{III}\,y^1 - K_{vv}^{III}\,x^1 - K_{v\gamma}^{III}$	$K_{uw}^{III}\,y^1 - K_{vw}^{III}\,x^1 - K_{w\gamma}^{III}$	$K_{u\alpha}^{III}\,y^1 - K_{v\alpha}^{III}\,x^1 - K_{\alpha\gamma}^{III}$	$K_{u\beta}^{III}$

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α_1	β_1	γ_1	u_2	v_2	
	$K_{u\beta}^{IV}$	$K_{u\gamma}^{IV}$	$-K_{uu}^{II}$	$-K_{uv}^{II}$	$-K_{uw}^{II}$
	$K_{v\beta}^{IV}$	$K_{v\gamma}^{IV}$	$-K_{uv}^{II}$	$-K_{vv}^{II}$	$-K_{vw}^{II}$
	$K_{w\beta}^{IV}$	$K_{w\gamma}^{IV}$	$-K_{uw}^{II}$	$-K_{vw}^{II}$	$-K_{ww}^{II}$
$I_x^I \omega^2$	$K_{\alpha\beta}^{IV} + I_{xy}^I \omega^2$	$K_{\alpha\gamma}^{IV} + I_{xz}^I \omega^2$	$K_{uv}^{II} z^{II} - K_{uw}^{II} y^{II} - K_{u\alpha}^{II}$	$K_{vv}^{II} z^{II} - K_{vw}^{II} y^{II} - K_{v\alpha}^{II}$	$K_{vw}^{II} z^{II}$
$+ I_{xy}^I \omega^2$	$K_{\beta\beta}^{IV} - I_y^I \omega^2$	$K_{\beta\gamma}^{IV} + I_{yz}^I \omega^2$	$K_{uw}^{II} x^{II} - K_{uu}^{II} z^{II} - K_{u\beta}^{II}$	$K_{vw}^{II} x^{II} - K_{uv}^{II} z^{II} - K_{v\beta}^{II}$	$K_{ww}^{II} x^{II}$
$I_{xz}^I \omega^2$	$K_{\beta\gamma}^{IV} + I_{yz}^I \omega^2$	$K_{\gamma\gamma}^{IV} - I_z^I \omega^2$	$K_{uu}^{II} y^{II} - K_{uv}^{II} x^{II} - K_{u\gamma}^{II}$	$K_{uv}^{II} y^{II} - K_{vv}^{II} x^{II} - K_{v\gamma}^{II}$	$K_{uw}^{II} y^{II}$
	$-K_{u\beta}^{III}$	$-K_{u\gamma}^{III}$	$K_{uu}^{II} - m_2 \omega^2$	K_{uv}^{II}	K_{uw}^{II}
	$-K_{v\beta}^{III}$	$-K_{v\gamma}^{III}$	K_{uv}^{II}	$K_{vv}^{II} - m_2 \omega^2$	K_{vw}^{II}
	$-K_{w\beta}^{III}$	$-K_{w\gamma}^{III}$	K_{uw}^{II}	K_{vw}^{II}	$K_{ww}^{II} - m$
$- K_{w\alpha}^{III} y^I - K_{\alpha\alpha}^{III}$	$K_{v\beta}^{III} z^I - K_{w\beta}^{III} y^I - K_{\alpha\beta}^{III}$	$K_{v\gamma}^{III} z^I - K_{w\gamma}^{III} y^I - K_{\alpha\gamma}^{III}$	$K_{u\alpha}^{II}$	$K_{v\alpha}^{II}$	$K_{w\alpha}^{II}$
$- K_{u\alpha}^{III} z^I - K_{\alpha\beta}^{III}$	$K_{w\beta}^{III} x^I - K_{u\beta}^{III} z^I - K_{\beta\beta}^{III}$	$K_{w\gamma}^{III} x^I - K_{u\gamma}^{III} z^I - K_{\beta\gamma}^{III}$	$K_{u\beta}^{II}$	$K_{v\beta}^{II}$	$K_{w\beta}^{II}$
$- K_{v\alpha}^{III} x^I - K_{\alpha\gamma}^{III}$	$K_{u\beta}^{III} y^I - K_{v\beta}^{III} x^I - K_{\beta\gamma}^{III}$	$K_{u\gamma}^{III} y^I - K_{v\gamma}^{III} x^I - K_{\gamma\gamma}^{III}$	$K_{u\gamma}^{II}$	$K_{v\gamma}^{II}$	$K_{w\gamma}^{II}$

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	v_2	w_2	α_2	β_2	γ_2
	$-K_{uv}^{II}$	$-K_{uw}^{II}$	$-K_{u\alpha}^{II}$	$-K_{u\beta}^{II}$	$-K_{u\gamma}^{II}$
	$-K_{vv}^{II}$	$-K_{vw}^{II}$	$-K_{v\alpha}^{II}$	$-K_{v\beta}^{II}$	$-K_{v\gamma}^{II}$
	$-K_{vw}^{II}$	$-K_{ww}^{II}$	$-K_{w\alpha}^{II}$	$-K_{w\beta}^{II}$	$-K_{w\gamma}^{II}$
$^{II}_{\alpha}$	$K_{vv}^{II}\, z^{II} - K_{vw}^{II}\, y^{II} - K_{v\alpha}^{II}$	$K_{vw}^{II}\, z^{II} - K_{ww}^{II}\, y^{II} - K_{w\alpha}^{II}$	$K_{v\alpha}^{II}\, z^{II} - K_{w\alpha}^{II}\, y^{II} - K_{\alpha\alpha}^{II}$	$K_{v\beta}^{II}\, z^{II} - K_{w\beta}^{II}\, y^{II} - K_{\alpha\beta}^{II}$	$K_{v\gamma}^{II}\, z^{II} - K_{w\gamma}^{II}\, y^{II} -$
$^{II}_{\beta}$	$K_{vw}^{II}\, x^{II} - K_{uv}^{II}\, z^{II} - K_{v\beta}^{II}$	$K_{ww}^{II}\, x^{II} - K_{uw}^{II}\, z^{II} - K_{w\beta}^{II}$	$K_{w\alpha}^{II}\, x^{II} - K_{u\alpha}^{II}\, z^{II} - K_{\alpha\beta}^{II}$	$K_{w\beta}^{II}\, x^{II} - K_{u\beta}^{II}\, z^{II} - K_{\beta\beta}^{II}$	$K_{w\gamma}^{II}\, x^{II} - K_{u\gamma}^{II}\, z^{II} -$
$^{II}_{\gamma}$	$K_{uv}^{II}\, y^{II} - K_{vv}^{II}\, x^{II} - K_{v\gamma}^{II}$	$K_{uw}^{II}\, y^{II} - K_{vw}^{II}\, x^{II} - K_{w\gamma}^{II}$	$K_{u\alpha}^{II}\, y^{II} - K_{v\alpha}^{II}\, x^{II} - K_{\alpha\gamma}^{II}$	$K_{u\beta}^{II}\, y^{II} - K_{v\beta}^{II}\, x^{II} - K_{\beta\gamma}^{II}$	$K_{u\gamma}^{II}\, y^{II} - K_{v\gamma}^{II}\, x^{II} -$
	K_{uv}^{II}	K_{uw}^{II}	$K_{u\alpha}^{II}$	$K_{u\beta}^{II}$	$K_{u\gamma}^{II}$
	$K_{vv}^{II} - m_2\, \omega^2$	K_{vw}^{II}	$K_{v\alpha}^{II}$	$K_{v\beta}^{II}$	$K_{v\gamma}^{II}$
	K_{vw}^{II}	$K_{ww}^{II} - m_2\, \omega^2$	$K_{w\alpha}^{II}$	$K_{w\beta}^{II}$	$K_{w\gamma}^{II}$
	$K_{v\alpha}^{II}$	$K_{w\alpha}^{II}$	$K_{\alpha\alpha}^{II} - I_x^{II}\, \omega^2$	$K_{\alpha\beta}^{II} + I_{xy}^{II}\, \omega^2$	$K_{\alpha\gamma}^{II} + I_{xz}^{II}\, \omega^2$
	$K_{v\beta}^{II}$	$K_{w\beta}^{II}$	$K_{\alpha\beta}^{II} + I_{xy}^{II}\, \omega^2$	$K_{\beta\beta}^{II} - I_y^{II}\, \omega^2$	$K_{\beta\gamma}^{II} + I_{yz}^{II}\, \omega^2$
	$K_{v\gamma}^{II}$	$K_{w\gamma}^{II}$	$K_{\alpha\gamma}^{II} + I_{xz}^{II}\, \omega^2$	$K_{\beta\gamma}^{II} + I_{yz}^{II}\, \omega^2$	$K_{\gamma\gamma}^{II} - I_z^{II}\, \omega^2$

SAMPLE CALCULATION

Although the compound mounting problem chosen for solution resulted from a specific shipboard installation, it is unnecessary to discuss the equipment involved here. It is sufficient to state that the system was such that, at least within the range of vibration frequencies to be dealt with, both the assembly and the supporting cradle could be considered as rigid bodies. These are designated as Bodies I and II, in accordance with Figure 1.

It is assumed that the static problem has been previously solved, which means that the position of the center of gravity and the orientation of each body with respect to the hull is known. Then axes x_1, y_1, z_1 and x_2, y_2, z_2 are established with origins at the centers of gravity and known orientation with respect to the hull.

The masses and moments of inertia of the bodies were:

$$m_1 = 5.10 \text{ lb-sec}^2/\text{in.}$$
$$I_x^{I} = 307 \text{ lb-sec}^2 \text{ in.}$$
$$I_y^{I} = 10{,}080 \text{ lb-sec}^2 \text{ in.}$$
$$I_z^{I} = 10{,}080 \text{ lb.sec}^2 \text{ in.}$$
$$m_2 = 6.51 \text{ lb-sec}^2/\text{in.}$$
$$I_x^{II} = 1768 \text{ lb-sec}^2 \text{ in.}$$
$$I_y^{II} = 3150 \text{ lb-sec}^2 \text{ in.}$$
$$I_z^{II} = 4390 \text{ lb-sec}^2 \text{ in.}$$

The products of inertia for both bodies are zero; i.e.,

$$I_{xy}^{I} = I_{xz}^{I} = I_{yz}^{I} = 0$$

and

$$I_{xy}^{II} = I_{xz}^{II} = I_{yz}^{II} = 0$$

The lower set of mountings consisted of four identical mountings with axial spring constants $k_a = 3370$ lb/in. and radial spring constants $k_r = 2000$ lb/in. The coordinates of the effective points of attachment of these mountings with respect to x_1, y_1, z_1, used to evaluate the K^{I}'s, were:

Mounting	x	y	z
1	44.5	-7.5	-7.35
2	44.5	7.5	-7.35
3	-44.5	7.5	-7.35
4	-44.5	-7.5	-7.35

The orientation of the axes of all four mountings was:

$$\cos \phi_x = 0$$
$$\cos \phi_y = 0$$
$$\cos \phi_z = 1$$

The upper set of mountings consisted of four identical mountings with axial spring constants $k_a = 2480$ lb/in. and radial spring constants $K_r = 1195$ lb/in. The coordinates of the effective points of attachment of these mountings with respect to x_1, y_1, z_1, used to evaluate the K^{III}'s, were:

Mounting	x	y	z
1	44.5	-7.5	7.28
2	44.5	7.5	7.28
3	-44.5	7.5	7.28
4	-44.5	-7.5	7.28

The coordinates of the effective points of attachment of the upper set of mountings with respect to x_2, y_2, z_2, used to evaluate the K^{II}'s, were:

Mounting	x	y	z
1	33.44	-7.5	-20.28
2	33.44	7.5	-20.28
3	-55.56	7.5	-20.28
4	-55.56	-7.5	-20.28

The orientation of the axes of all four mountings was:

$$\cos \phi_x = 0$$
$$\cos \phi_y = 0$$
$$\cos \phi_z = 1$$

Table 1 shows the printed output of the digital computer for this system. Here U, V, and W represent u, v, and w; and A, B, and G represent α, β, and γ. The table gives the normal-mode pattern corresponding to each of the twelve natural frequencies of the compound system. Only the relative magnitudes of the values given are significant, but it is to be noted that, since the input data were given in inch-pound-second units, the values of A, B, and G will be in radians only when the values of u, v, and w are expressed in inches.

In Table 1 all displacements are expressed as numbers between 1 and 10 followed by an exponent expressed in powers of 10. When the system has planes of vibrational symmetry which coincide with certain planes of the coordinate system chosen, as in this example, the normal modes will not actually involve all 12 coordinates. However, the coordinates that are theoretically zero appear in the output data as very small numbers (with exponents from 10^{-6} to 10^{-10}).

TABLE 1

Output Data Sheet from Digital Computer for Compound Isolation Mounting System

On this UNIVAC Data Sheet

$U1, U2, V1, V2, W1, W2 = u_1, u_2, v_1, v_2, w_1, w_2$

$A1, A2, B1, B2, G1, G2 = \alpha_1, \alpha_2, \beta_1, \beta_2, \gamma_1, \gamma_2$

```
                                     NATURAL FREQUENCY =  1.0532E 00

U1 = -4.5647E-09   V1 =  1.6543E-01   W1 = -1.2176E-09   A1 = -1.7031E-02   B1 = -1.6980E-10   G1 =  2.0545E-04
U2 = -2.4643E-08   V2 =  1.0000E 00   W2 =  6.6157E-09   A2 = -3.1804E-02   B2 = -7.6649E-10   G2 =  5.3998E-04

                                     NATURAL FREQUENCY =  4.9313E 00

U1 =  2.0422E-08   V1 = -1.0000E 00   W1 = -1.9059E-08   A1 =  3.2187E-02   B1 = -3.8411E-10   G1 =  2.8907E-02
U2 =  1.7006E-08   V2 = -1.9301E-01   W2 = -2.2791E-08   A2 = -3.7325E-02   B2 = -1.0429E-09   G2 =  4.8550E-02

                                     NATURAL FREQUENCY =  4.4979E 00

U1 = -1.6509E-08   V1 =  1.0000E 00   W1 =  3.3550E-08   A1 = -2.3312E-02   B1 =  5.1206E-12   G1 =  1.6002E-02
U2 = -1.7873E-08   V2 =  4.9157E-01   W2 =  5.5238E-08   A2 =  7.5920E-02   B2 =  7.6875E-10   G2 =  2.9549E-02

                                     NATURAL FREQUENCY =  4.2694E 00

U1 =  1.0902E-01   V1 =  5.4165E-06   W1 =  4.7755E-01   A1 = -1.1359E-07   B1 = -1.9859E-03   G1 =  1.0862E-07
U2 =  1.2569E-01   V2 =  3.4876E-06   W2 =  1.0000E 00   A2 =  4.2680E-[illegible]   B2 = -4.5394E-03   G2 =  2.2085E-07

                                     NATURAL FREQUENCY =  2.9095E 00

U1 =  3.8188E-01   V1 =  1.0805E-07   W1 = -2.2770E-02   A1 = -3.0759E-09   B1 =  3.8880E-03   G1 =  4.1831E-09
U2 =  1.0000E 00   V2 =  2.0971E-07   W2 = -1.2325E-01   A2 =  3.7221E-09   B2 =  6.6409E-03   G2 =  4.9884E-09

                                     NATURAL FREQUENCY =  7.0999E 00

U1 =  1.0000E 00   V1 =  3.8192E-09   W1 = -3.6809E-01   A1 = -2.8822E-10   B1 = -2.4395E-02   G1 =  1.3251E-09
U2 = -5.5179E-02   V2 = -4.8603E-10   W2 = -9.4632E-03   A2 =  1.4672E-09   B2 = -3.5899E-02   G2 =  2.5198E-09

                                     NATURAL FREQUENCY =  8.8109E 00

U1 = -1.0000E 00   V1 = -7.2431E-08   W1 = -1.4959E-01   A1 =  1.2539E-09   B1 = -1.4718E-02   G1 = -1.3096E-09
U2 =  4.2582E-01   V2 =  3.4766E-08   W2 =  1.6123E-02   A2 =  4.5638E-09   B2 = -1.2051E-02   G2 =  6.2374E-09

                                     NATURAL FREQUENCY =  9.2613E 00

U1 = -3.3098E-07   V1 = -1.0000E 00   W1 = -1.3426E-07   A1 =  9.9297E-03   B1 = -8.9764E-09   G1 = -1.9950E-02
U2 =  1.5630E-07   V2 =  4.4698E-01   W2 =  2.0288E-08   A2 =  3.5788E-02   B2 = -9.4165E-09   G2 =  1.6612E-02

                                     NATURAL FREQUENCY =  1.0329E 01

U1 = -7.9078E-08   V1 =  1.0000E 00   W1 = -1.2661E-07   A1 =  2.0667E-02   B1 = -4.0627E-09   G1 = -2.6930E-02
U2 =  4.1458E-08   V2 = -4.4734E-01   W2 =  3.3406E-08   A2 = -3.7733E-02   B2 = -5.5651E-09   G2 =  4.5441E-02

                                     NATURAL FREQUENCY =  1.1588E 01

U1 =  2.9601E-02   V1 =  3.7010E-09   W1 =  1.0000E 00   A1 = -6.5792E-09   B1 = -7.1256E-03   G1 =  2.2040E-09
U2 = -4.1866E-03   V2 = -8.8460E-09   W2 = -3.9279E-01   A2 =  1.9249E-09   B2 =  2.3822E-03   G2 =  5.6136E-09

                                     NATURAL FREQUENCY =  1.3047E 01

U1 = -7.5087E-08   V1 = -7.7220E-01   W1 =  2.6058E-07   A1 = -1.0000E 00   B1 = -1.0471E-08   G1 = -5.6803E-03
U2 =  6.4210E-08   V2 = -8.8023E-01   W2 = -1.3766E-07   A2 = -1.9893E-02   B2 = -1.9108E-08   G2 =  2.4343E-02

                                     NATURAL FREQUENCY =  1.5798E 01

U1 = -3.8478E-01   V1 =  5.2573E-10   W1 =  1.0000E 00   A1 =  5.1262E-10   B1 =  6.9911E-02   G1 =  9.1037E-10
U3 =  3.2110E-01   V2 =  1.6005E-09   W2 = -5.7326E-01   A2 =  8.4363E-10   B2 = -1.9290E-01   G2 =  1.0862E-09
DUMP CONVERSION STARTED
```

Table 2 gives the essential information contained in Table 1 with the small quantities deleted and the exponents replaced by the appropriate shift in the decimal points.

TABLE 2

Normal Mode Patterns in Condensed Form for Sample Compound Isolation Mounting System

The first number applies to the cradle and the second to the assembly; the calculation was made in inch-pound-second units.

Natural Frequency cps	u	v	w	α	β	γ
1.05	- -	0.165 1.000	- -	-0.0170 -0.0318	- -	0.00021 0.00054
2.91	0.382 1.000	- -	-0.0228 -0.1233	- -	0.00389 0.00664	- -
4.27	0.109 0.126	- -	0.478 1.000	- -	-0.00199 0.00454	- -
4.50	- -	1.000 0.492	- -	-0.0233 0.0759	- -	0.0160 0.0296
4.93	- -	-1.000 -0.194	- -	0.0322 -0.0373	- -	0.0289 0.0486
7.10	1.0000 -0.0552	- -	-0.368 0.095	- -	-0.0244 -0.0359	- -
8.81	-1.000 0.426	- -	-0.1496 0.0161	- -	-0.0147 -0.0121	- -
9.26	- -	-1.000 0.447	- -	0.00993 0.03579	- -	-0.0200 0.0166
10.33	- -	1.000 -0.447	- -	0.0206 0.0378	- -	-0.0269 0.0454
11.59	0.0296 -0.0042	- -	1.000 0.393	- -	-0.00713 0.00238	- -
13.05	- -	-0.772 -0.860	- -	-1.0000 -0.0197	- -	-0.00568 0.02434
15.80	-0.585 0.321	- -	1.000 -0.573	- -	0.0699 -0.1929	- -

DISCUSSION AND CONCLUSIONS

This report is concerned chiefly with the mathematical solution of a basic problem in vibration. It need hardly be emphasized here that it is possible to obtain such solutions only by idealizing the actual shipboard installation. Only if the assembly and the cradle are sufficiently rigid in relation to the flexibility of the mountings to be installed in the ship, will the analysis given in this report be meaningful. It is distinctly in the interest of the designer to ensure that this condition is fulfilled, for he will then have assurance that the desired degree of isolation from hull vibration will be realized. An important extension of the problem not explored in this report is the case in which the hull structure which supports the mountings carrying the cradle cannot be assumed rigid.

Although in the majority of cases planes of symmetry will exist as in the example presented here, the equations discussed and the coding for digital solution are in the most general form and permit any orientation of the assumed axes (provided the two pairs remain parallel) and any degree of asymmetry either of the cradle or of the assembly.

The treatment of this problem by means of an electrical analog is discussed in Reference 3.

ACKNOWLEDGMENTS

The dynamical matrix derived in this report was verified by Mr. A.O. Sykes by an independent method. The problem was coded for digital solution by Mr. L. Katz, who also solved the prototype example and verified that the one-body problem previously treated at the Model Basin could also be handled by this coding. Mr. R.C. Leibowitz checked the analysis given in this report.

REFERENCES

1. Vane, F.F., "A Guide for the Selection and Application of Resilient Mountings to Shipboard Equipment," David Taylor Model Basin Report 880, Revised (Feb 1958).

2. Bureau of Ships letter SS427 (375) Serial 375-182 of 26 May 1959 to David Taylor Model Basin.

3. Ryder, F.L. and Zaid, M., "Direct Electrical Analogs of Double 6-Degree-of-Freedom System," Report on Contract Nonr-2952(00) (X), Scientific Research Staff, Republic Aviation Corporation, Farmingdale, New York (25 Feb 1960).

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